# Thermal Evolution of Venus: A Preliminary Study Based on Tectonic Feature Spacing

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## Introduction

The surface of Venus consists predominantly of structures formed since the 300-500 ma resurfacing event [1]. Subsequent to this event, the lithosphere underwent a period of rapid cooling. This cooling resulted in a decrease in the global thermal gradient over time.

## Overview

Tectonic features form as a result of small instabilities in the lithosphere. As these features grow, the nucleation distance of new features is controlled by the rheology of the lithosphere. For example, in a region undergoing extension, the distance each fracture forms from the next is directly proportional to the thickness of the brittle layer. However, fluctuations in the thermal gradient may produce corresponding fluctuations in the depth of the brittle-ductile transition.

There are several models constraining the nucleation distance of tectonic features. The shear-lag model of Banerdt and Sammis is independent of brittle layer depth [2]. This is true for a region that has a thin brittle layer in frictional contact with the substrate. Johnson and Sandwell propose that heating of the lithosphere causes an increase in the depth of brittle failure [3]. This failure occurs when the thermal stress exceeds the yield strength of the lithosphere. Zuber and Parmentier suggest that tectonic features on Venus form at two discrete spacings, one for each brittle layer of the lithosphere [4]. This is called the dominant wavelength model, and assumes a strong-weak-strong layering of the Venusian lithosphere. In this case, a decrease in thermal gradient would result in an increase in depth of the brittle layer. These models can be applied to structural units on Venus that have formed since resurfacing to show the change in the thermal gradient with time.

This study examines the relationship of tectonic feature spacing with age. We studied eight different samples of stratigraphic units identified by Basilevsky and Head [5]. The length of feature spacing was measured for each of these samples. Assuming a cooling lithosphere, we were looking for either a decrease in feature spacing, which would agree with the heated lithosphere model, or an increase in spacing which would conform to the dominant wavelength model. We did not consider the shear-lag model because the features produced by this model are produced locally, and our samples were selected on the basis that the features were a result of global effects.

## Measurement of Spacing

For this study, measurements of feature spacing were taken for eight different unit types: COaf (fractures of coronae annulae), COar (ridges associated with coronae annulae), COdf (densely fractures terrain associated with coronae), F (fractures), Fra (rift associated fractures), Pdf (densely fractured terrain), Pwr (plains with wrinkle ridges), and RB (ridge belts). These units were located on Venus using Magellan C1-MIDR and F-MIDR images.

To measure spacing, intensity profiles were generated along a cross section drawn perpendicular to the strikes of the features. The bright areas on the features showed up as peaks in the pixel data. The number of peaks in each plot was divided by the length of the cross section to give an average spacing for the plot. Discrete spacings were also tabulated by measuring the distance between each peak on the intensity profile.

## Results

The final results for the spacing measurements are given in Table 1. Splitting these units up into categories based on deformation and relative age gives three different groups. Group I consists of COdf and Pdf. These unit types are formed by extension. RB, Pwr, COar form Group II. This group is of intermediate age and is a result of compression. Group III (COaf, F, and Fra) is the youngest group and is formed by extension.

These three groupings can then be compared to the deformational history given by Basilevsky and Head. Group I falls into a period of mantle upwelling and regional extension. Group II formed after the new plains cooled and thickened. Group III occurs after compression, during periods of isolated volcanism and minor extension. This pattern is given by the column in Figure 1.

Examining the data in each group reveals an interesting trend. In Group I, fracture spacing increases from a low of 1.48 km for Pdf to 3.27 km for COdf. This is typical of a steadily decreasing thermal gradient as the crust cools and thickens. In Group II, the numbers again increase from 3.05 km for RB to 5.71 km for Pwr. Here the crust is continuing to thicken and cool. One anomalous data point is COar (1.78 km). In Group III, the spacing again increases and decreases over time from COaf (3.09 km) to F (9.15 km) to Fra (3.16 km). This shows an overall decrease in thermal gradient with local increases.

## Conclusion

Though there are some regional trends within the data there is no strong correlation to a global pattern. However, in those areas studied that included multiple periods of deformation there was a consistent increase in spacing seen between the oldest and youngest features. This would lead us to conclude that there was a regional decrease in the thermal gradient consistent over several samples of the surface of Venus.

## References

[1] Strom, et. al. (1994) J. Geophys. Res., 99, 10899-10926. [2] Banerdt, W.B. and Sammis, C.G (1992) J. Geophys. Res., 97, 16149-16166. [3] Johnson, C.L., and Sandwell, D.T. J. Geophys. Res., 97, 13601-13610. [4] Zuber, M. T., and Parmentier, E. M. (1990) Icarus, 85, 180-308. [5] Basilevsky, A. T., and Head, J.W. (1995) Earth, Moon, and Planets, 66, 285-336.

Notes: This project was completed at Brown University under the Planetary Geology and Geophysics Undergraduate Research Program .

Oldest

| Group | Deformation | Thermal Gradient |
|---|---|---|
| I<br>Pdf<br>COdf | Post tessera formation extension | Starts high; slowly decreases |
| II<br>RB<br>Pwr<br>Coar | Lithospheric cooling and thickening compression | Continues to decrease globally |
| III<br>COaf<br>F<br>Fra | Isolated volcanism minor extension | Decreases globally; Increases locally |

Youngest

Figure 1. Column depicting relationship between groups and deformational history.

| Name | N | Average, km | Tabulated mean,km | Error | Min | Max | Variance |
|---|---|---|---|---|---|---|---|
| Pdf | 221 | 1.65 | 1.48 | 1.17 | 0.275 | 7.01 | 79.05 |
| COdf | 103 | 3.17 | 3.27 | 2.28 | 0.64 | 12.3 | 69.72 |
| RB | 48 | 2.66 | 3.05 | 1.75 | 0.573 | 7.15 | 57.38 |
| Pwr | 44 | 6.37 | 5.71 | 2.95 | 2.04 | 14 | 51.66 |
| COar | 156 | 2.06 | 1.78 | 1.25 | 0.655 | 7.88 | 70.22 |
| COaf | 95 | 4.26 | 3.09 | 2.52 | 0.473 | 12.9 | 81.55 |
| F | 45 | 6.94 | 9.15 | 8.57 | 1.44 | 34.3 | 93.66 |
| Fra | 132 | 3.05 | 3.16 | 2.58 | 0.808 | 19.6 | 81.65 |

Table 1. Results of spacing measurements.